A Study of Dielectric Relaxation Process in Biological Complex Systems

Synopsis

Submitted to

SWAMI RAMANAND TEERTH MARATHWADA UNIVERSITY, NANDED

For the registration of the topic for
Doctor of Philosophy
in the subject of **PHYSICS**
(Faculty of Science)

(Mr Dilip Rathod)
Research Student

(Dr Y S Joshi)
Research Guide,
Asst. Professor,
L.B.S. Mahavidyalaya,
Dharmabad.
(Mobile: 9405362172)

Abstract of proposed work plan/problem:

“A Study of Dielectric relaxation process in Biological Complex Systems”

1. Introduction :

Biomolecules are the molecules that are present in living organism which includes large macromolecules such as carbohydrate, proteins, lipids, nucleic acids as well as small molecules vitamins, primary metabolites etc. Amino acids are the building blocks for peptides and proteins which plays an important role in metabolism. In living organism, there are twenty different amino acids are found. They can connect to each other via peptide bonds to form long chains. Another biomolecules, Proteins are consists of thousands of amino acids. Shorter chains of up to few hundred amino acids are referred as peptides. The sequence of the amino acids within the molecule is essential for the structure and function of proteins and peptides in biological processes. Dielectric permittivities are intrinsic properties that determine the interaction of electromagnetic energy with materials. Generally, the permittivites are represented by the complex term. The frequency (ω) dependant relative permittivity $\varepsilon^*(\omega) = \varepsilon'(\omega) - j\varepsilon''(\omega)$, where the real part ε' is dielectric permittivity, it is associated with the capability of energy storage in the material and the imaginary part ε" is the dielectric loss which is associated with energy dissipation or loss in the material in the form of heat. Dielectric spectroscopy (DS) is a non destructive, very sensitive and with high accuracy technique to investigate complex systems and it is particularly suitable in studying biological complex systems. Solutions of biomolecules at radio frequencies exhibit typical dielectric relaxations due to orientation polarization. From the dispersion curve it is possible to determine two significant parameters characterizing conformation and structure of a biomolecule: the effective hydrodynamic radius and the electric

dipole moment. The technique is highly sensitive and able to evidence small effects on the overall conformation of the macromolecule [1].

In this work, the measurement of complex permittivity spectra at various frequency range of some biomolecules and their binary mixtures is supposed to be carry out. Further, these permittivity spectra will be used to extract the dielectric parameters using suitable empirical model. It provides useful information about structural behavior, the interactions between the various species present in the liquid of interest and conformation of complex structures.

2. Review of Literature and Development in the subject (Previous work done in the relevant area)

The frequency dependent dielectric permittivity is an important physiochemical property. For mixtures of fluids and solutions it provides useful information about the interactions between the various species present in the liquid of interest [2-4]. Literature reviews show abundance study of dielectric measurements of the complex systems (carbohydrates, amino acids, proteins etc.) and its aqueous solutions to understand their dynamical and structural behavior using dielectric spectroscopy [5-23]. Recently, systematic study of the dielectric properties of eight amino acids was reported by Rodriguez-Arteche et al.[24]. Over the past few decades, dielectric spectroscopy has been significantly used to realize the fundamentals properties such as mechanism of relaxation of biomolecules as well as practical aspects for new materials and technologies [25]. Recently, it is used to study the glass transitions in aqueous solutions of proteins, interaction between the proteins and nanotubes, the folding-unfolding process of proteins, dynamic of water in protein-water mixtures, protein- protein interactions in solutions for biosensor applications, protein crypreservation in an aqueous solutions and protofilament formation[26-33].

3. Objectives of Research/Proposed hypothesis:

- The precise measurement of complex permittivity of the suitable biological complex systems and their solutions.
- Determine the static dielectric constant, relaxation time, high frequency dielectric permittivity through least square fit method by using experimental data.
- To measure the refractive indices.
- To study dynamics in the structure of biomloecules and their solutions.

4. Methodology

For high frequency dielectric measurement Time Domain Reflectometry (TDR) technique is very much useful. The principle of working this technique is as: A fast rising 250mv voltage pulse with repetition frequency of few KHz with rise time of picosecond is allowed to transmit through a coaxial line with characteristic impedance 50 ohm. The co-axial cable semirigid, copper, with flat end can be used. Sampling oscilloscope monitors changes in the pulse after reflection from the end of line. Reflected pulse without sample $R_1(t)$ and with sample $R_x(t)$ were digitized with suitable sampling points in the window. These recorded pulses are added [$q(t) = R_1(t) + R_X(t)$] and subtracted [$p(t) = R_1(t) - R_X(t)$]. Further the Fourier transformations of p(t) and q(t) were performed in the frequency range 10MHz to 30GHz results in 'raw spectra'. These 'raw' spectra may contain errors and spurious reflections which can be corrected using calibration method to obtain the complex permittivity spectra [34].

The low frequency dielectric measurement can be done using Precision LCR meter (Frequency Domain) technique. The complex relative dielectric function $\varepsilon^*(\omega)$ of liquid samples can be measured in the frequency range few Hz to some MHz. In this technique, the capacitance and parallel resistance of the liquid dielectric test fixture without and with samples were

measured to compensate for a short [35-36]. The refractive index of the liquid sample will be measured using Abbe's refractometer.

5. Importance of study/society application:

The following scientists are doing research in this field at national/international level

- **International status:**

1. Y Feldman, Deptt. of Applied Physics, The Hebrew University of Jerusalem, Jerusalem, Israel.
2. N Shiyanshiki, University of Tokyo, Tokyo, Japan
3. S Yagihara, University of Tokyo, Tokyo, Japan
4. U Kaatze, Drittes Physikalisches Institut Georg-August-Universität Göttingen, Germany.

- **National Status:**

1. S C Mehrotra, Dr. BAMU, Aurangabad(MS).
2. R J Sengwa, JNV University, Jodhpur, Rajhsthan.
3. A C Kumbharkhane, SRTM University, Nanded (MS).
4. V A Rana, Gujrat University, Ahmedabad (Gujrat).

- **Significance of the study**

Dielectric Spectroscopy provides quickly and accurately frequency dependant permittivity spectra for biological systems such as carbohydrates, amino acids, proteins, DNA etc. Due to its accuracy, flexibility, large application conditions and potential for automated measurement, reflectometry has become one of the most attractive methods for monitoring applications. Generally, the dielectric study of any polar molecule in aqueous solutions is aimed at evaluating its dipole moment and relaxation time which is directly related to its volume. This study is useful in order to explain the various relaxation processes in biomolecules as well as their aqueous

solutions. From the analysis of dielectric spectra one can found the orientation of the molecules, dipole-dipole interactions of the biomolecules.

6. Proposed work plan/Formulation and structure of study:

- **First Year:** To understand the basic concept essential to explain the dielectric properties of the biological systems. To study theoretical background of research problem and detail literature survey.
- **Second Year:** To choose suitable biological complex systems and their solutions for dielectric measurement. To study dielectric dispersion and relaxation of these systems at different frequency ranges. To evaluate the dielectric properties such as static dielectric constant, relaxation time dielectric constant at high frequency for these systems. To measure the refractive indices and densities of these liquids.
- **Third Year:** Discuss the orientation among the molecules, dipole-dipole interactions and conformations of studied complex biological systems and their solutions. The work will be published by writing research papers or presenting the work in conference/seminars. Finally, conclude the research work by completion of thesis.

7. References:

[1] A Bonincontro, S Cinelli, G Onori, A Stravato, Bio. Phys. J. 86 (2004) 1118.

[2] J B Hasted, *Aqueous Dielectrics,* Chapman and Hall, London, (1973).

[3] P A Madden, D Kivelson, Adv. Chem. Phys. 56 (1984) 467.

[4] J P Hansen, I R McDonald, *Theory of Simple Liquids*, 2nd ed. Academic, London, (1986).

[5] R Pethig, *Dielectric and Electronic Properties of Biological Materials* Wiley, Chichester, (1979).

[6] S Boresch, M Willensdorfer, O Steinhauser, J. Chem. Phys., 120 (7) (2004) 3333.

[7] S Cerveny[1], A Alegría, L Leza, J Colmenero, 5th International Conference on Broadband Dielectric Spectroscopy and Its Applications (BDS2008), Lyon : France (2008).

[8] T Sato, R Buchner, S Fernandez, A Chiba, W Kunz, J. Mol. Liq. 117 (2005) 93.

[9] S Bettati, C Viappiani, A Mozzarelli, Biochimica et Biophysica Acta 1794 (2009) 1317.

[10] D J Bakewell, I Ermolina, H Morgan; J Milner, Y Feldman, Biochimica et Biophysica Acta 1493 (2000) 151.

[11] J G Kirkwood, J. Chem. Phys. 2 (1934) 315.

[12] J Wayman, T L McMeekin, J. Am. Chem. Soc. 55(3) (1933) 915.

[13] J Wayman, J. Am. Chem. Soc. 56(3) (1934) 536.

[14] M W Aaron, E Grant, Tans. Faraday Soc. 63 (1967) 2177.

[15] M Kumazaki, S Sugai, J. Phys. Soc. Jpn. 37 (1972) 785.

[16] J B Bateman, C. Gabriel, E H Grant, J. Chem. Soc. Faraday Trans. 86 (1990) 3577.

[17] M Suzuki, J. Shigematsu, Y Fukunishi, T Kodama, J. Phys. Chem. B 101(19) (1997) 3839.

[18] X Liao, G S V Raghvan, G Wu, V A Yaylayan, 107 (1-2) (2003) 15.

[19] F Bordi, C Cametti, A Motta, J. Polym. Sci. B: Polym. Phys. 37(21) (1999) 3123.

[20] H Jansson, J Swenson, Biochimica et Biophysica Acta 1804 (2010) 20.

[21] E Pirogova, G P Simon, I Cosic, IEEE Transc. Nanobiosci, 2(2) (2003) 63.

[22] M P Longinotti, H R Corti, J J. de Pablo, Carbohydrate Research 343 (2008) 2650.

[23] C G Akode, K S Kanse, M P Lokhande, A C Kumbharkhane, S C Mehrotra, Pramana J. Phys. 62(4) (2004) 973.

[24] I Rodriguez-Arteche, S Cerveny, A Algeria, J Colmenero, Phys. Chem. Chem. Phys. 14 (2012) 11352.

[25] V Raicu, Y Feldman, *Dielectric Relaxation in Biological Systems*, 1st ed. Oxford University Press, UK (2015).

[26] N Shinyashiki, W Yamamoto, A Yokohama, T Yoshonari, S Yagihara, R Kita, K L Negai, S Capaccicoli, J. Phys. Chem. B 113 (2009) 14448.

[27] F Bomboi, F Taradani, D Gozzoli, A Bonincontro, C L Mesa, Colloids Surf. B: Biointerfaces, 108 (2013) 16.

[28] A Sanfeld, K Sefiane, A Steinchen, Adv. Colloid Interface Sci. 169 (2011) 26.

[29] Y Maruyama, Y Numamoto, H Saito, R Kita, N Shinyashiki, S Yagihara, M Fukuzaki, Colloids Surf. A: Physicochem. Eng. Aspects 440 (2014) 42.

[30] L Yu, X Hu, D Kaplan, P Cebe, Biomicromolecules, 11 (2010) 2766.

[31] H Sedwick, J E Cameron, W C K Poon, S U Egehalf, J. Chem. Phys. 127 (2007) 125102.

[32] B A Mazzeo, A J Flewitt, Appl. Phys. Lett. 90 (2007) 123901.

[33] H Sanbria, J H Miller, A Mershin, R F Luduena, A A Kolomenski, H A Schuessler, D V Nanopoulous, Biophys. J. 90 (2006) 4644.

[34] A C Kumbharkhane, Y S Joshi, S C Mehrotra, S Yagihara, S Sudo, Physica B 421 (2013) 1.

[35] Y S Joshi, K S Kanse, D N Rander A C Kumbharkhane, Indian J. Pure & Appl. Phys. 54 (2016) 621.

[36] R J Sengwa, S Sankhla, N Shinyashiki, J Sol Chem, 37 (2008) 137.

Mr Dilip Rathod
Research Student

Dr Y S Joshi
Research Guide